<u>ENCLOSURE 10</u>

To Determine Time Limit for Exposure of the Fuel Cladding to Oxidizing Atmosphere for the 24P and 32P DSCs Stored at the CCNPP ISFSI Site – Non-Proprietary

Calvert Cliffs Nuclear Power Plant, LLC
June 14, 2013

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NON - PROPRIETARY VERSION

AREVA TRANSNUCLEAR INC.	**Form 3.2-1** **Calculation Cover Sheet** **TIP 3.2 (Revision 6)**	**Calculation No.:** 10955-0402 **Revision No.:** 1 **Page: 1 of 23**
DCR NO (if applicable) : 10955-003	**PROJECT NAME:** License Renewal for CCNPP	
PROJECT NO: # 10955	**CLIENT:** CENG - Calvert Cliff Nuclear Power Plant (CCNPP)	

CALCULATION TITLE:

To Determine Time Limit for Exposure of the Fuel Cladding to Oxidizing Atmosphere for the 24P and 32P DSCs Stored at the CCNPP ISFSI Site

SUMMARY DESCRIPTION:

1) Calculation Summary

This calculation determines the time limit for exposure of the fuel cladding to the oxidizing atmosphere due to a hypothetical stress corrosion cracking (SCC) that leads to a compromised DSC shell and release of helium after the long-term storage of the 24P and 32P Dry Shielded Canisters (DSCs) located at the Calvert Cliffs Nuclear Power Plant (CCNPP) Independent Spent Fuel Storage Installation (ISFSI) Site.

2) Storage Media Description

Secure network server initially, then redundant tape backup

If original issue, is licensing review per TIP 3.5 required?

Yes ☐ **No** ☒ **(explain below)** **Licensing Review No.:**______________

This calculation is prepared to support a Site Specific License Application by CCNPP that will be reviewed and approved by the NRC. Therefore, a 10CFR72.48 licensing review per TIP 3.5 is not applicable.

Software Utilized (subject to test requirements of TIP 3.3):	**Version:**
ANSYS	10.0
Calculation is complete: Originator Name and Signature: Davy Qi	Date: 06/06/2013
Calculation has been checked for consistency, completeness and correctness: Checker Name and Signature: Venkata Venigalla	Date: 06/06/2013
Calculation is approved for use: Project Engineer Name and Signature: Girish Patel	Date: 6/6/2013

REVISION SUMMARY

REV.	DESCRIPTION	Affected Pages	Affected Computational I/O
0	Initial Issue	All	All
1	Reference 6 is changed to revision 1	1-2, and 7	None

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1.0 PURPOSE

The welds on the DSC shells are potentially affected by the stress corrosion cracking (SCC) after long-term storage. Hypothetically, the DSC shell may be compromised due to SCC. Under this hypothetical condition the helium may get released from the DSC cavity and be replaced by air. This calculation determines the maximum exposure time that fuel cladding within the NUHOMS® 24P and 32P DSCs during long-term storage at the CCNPP ISFSI remain undamaged when exposed to an oxidizing atmosphere after the DSC shell is compromised due to stress corrosion cracking (SCC).

2.0 REFERENCES

1 Topical Report for the Nutech Horizontal Modular Storage System for Irradiated Nuclear Fuel, NUHOMS-24P, Nutech Engineers, Inc., NUH-002.0103, Revision 1A, July 1989.

2 Drawing, "NUHOMS-24P ISFSI DSC Carbon Steel Basket Assembly", Drawing No. BGE-02-1006, Revision 2.

3 Calculation, "24P Standard and Long Cavity Basket Thermal Analysis for Increased Burnup Fuel", Transnuclear Inc., Calculation No. NUH-HBU.0401, Revision 1.

4 Calculation, "Finite Element Model, Thermal Analysis", Transnuclear Inc., Calculation No. 1095-5, Revision 0.

5 Calculation, "Effective Fuel Properties for Vacuum Drying", Transnuclear, Inc., Calculation No. 1095-38, Revision 0.

6 Calculation, "Outer Surface Weld Temperature of the NUHOMS® 24P and 32P DSCs Stored at CCNPP ISFSI Site", Transnuclear, Inc., Calculation No. 10955-0401, Revision 1.

7 Electric Power Research institute, "Oxidation of Spent Fuel at Between 250 and 360°C", EPRI NP-4524, April 1986.

8 ANSYS computer code and On-Line User's Manuals, Versions 5.6 and 10.0.

9 Calvert Cliffs Independent Spent Fuel Storage Installation, Updated Safety Analysis Report, Rev 17.

10 SANDIA Report, SAND90-2406, "A Method for Determining the Spent Fuel Contribution to Transport Cask Containment Requirements," 1992.

11 Safety Analysis Report for NUHOMS-MP197 Transport Packaging, Transnuclear Inc., Rev. 11.

3.0 ASSUMPTIONS AND CONSERVATISM

3.1 24P DSC Model

The Calvert Cliffs Nuclear Power Plant (CCNPP) 24P DSC is very similar to the standardized NUHOMS® 24P DSC described in [3]. The assumptions and conservatisms for the standardized NUHOMS® 24P DSC model described in [3] are considered in this calculation with the exception of the dimensional differences noted in Table 4-1.

The open width of the guide sleeves for the CCNPP 24P DSC are 8.7" while the open width of the guide sleeves is 8.9" for the standardized NUHOMS® 24P DSC described in [3]. The effective fuel conductivities decrease as the open width of the guide sleeves increases. The effective fuel properties listed in Table 4-1 of [3] for the standardized NUHOMS® 24P DSC are conservatively assumed in this calculation to maximize the fuel cladding temperature for the CCNPP 24P DSC.

In finite element models of fuel assemblies, the effective fuel conductivity is calculated using SANDIA Report, SAND90-2406 [10] as follows.

$$k_{eff} = \frac{q''' a^2}{(T_c - T_o)}(0.29468)$$

q''' = volumetric heat generation rate
a = half of the compartment width
T_c = maximum center temperature (peak cladding temperature)
T_o = wall temperature

Rearranging the above equation as depicted below shows that the resulting temperature difference is proportional to the square of the compartment size.

$$(T_c - T_o) = \frac{q''' a^2}{keff}(0.29468)$$

Therefore, the conservatism in the model can be estimated based on the square ratio of the compartment size used in the model versus the real compartment size:

$(8.9/8.7)^2 = 1.046$ or 4.6%

The conservatism being introduced by use of the fuel effective thermal conductivites in the generic 24P DSC as opposed to those specific to the CCNPP 24P DSC is approximately 5%.

3.2 32P DSC Model

NUHOMS® 32P DSC is specifically designed for CCNPP. The same assumptions and conservatisms for the NUHOMS® 32P DSC described in [4] are considered in this calculation.

3.3 Fuel Oxidation Time Limit

The calculation of the fuel oxidation time limit is based on the maximum temperature of fuel rod which occurs at the middle section of the fuel rod. The incubation time as a function of temperature is based on the test data from the center of the rod samples as shown in Figure 3-9 of EPRI test report [7]. Although the cladding defects on the end samples propagated earlier than would be expected on the center of the rod as shown in Figure 3-9 of [7], the rod ends are much cooler, which results in longer time limits. The evalaution of the time limit for fuel oxidation using the test data for the center of the rods is therefore conservtaive.

4.0 DESIGN INPUT

4.1 Environmental Conditions and Heat Loads

It is expected that the maximum heat loads for 24P DSC and 32P DSC are reduced to approximately between 4 kW and 6 kW after long-term storage at the CCNPP ISFSI site. Therefore, heat loads of 4 kW to 6 kW are assumed for the 24P and 32P DSCs after long-term storage at the CCNPP ISFSI site when the DSC shell may hypothetically be compromised due to SCC. The results of this evaluation are valid for any 24P DSC and 32P DSC with maximum heat loads below 6 kW at CCNPP ISFIS site regardless of the storage time since the maximum heat loads as the used as inputs.

The DSC shell temperature profile for 6 kW heat load is retrieved directly from result files of the CFD model described in [6] and applied as a boundary condition for the 24P and 32P DSC models.

The DSC shell temperature profile for 4 kW heat load is recalculated using linear interpolation between the result files of the 2 kW and 6 kW heat loads taken from the CFD model described in [6]. The recalculated DSC shell temperature profile is applied as the boundary condition for the 24P and 32P DSC models.

4.2 DSC Dimensions

The CCNPP 24P DSC model is developed based on the standardized 24P DSC model [3] with the CCNPP 24P DSC dimensions as summarized in Table 4-1.

Table 4-1 24P DSC Dimensions for Standardized and the CCNPP DSC Models

Proprietary Information Withheld Pursuant to 10 CFR 2.390

The dimensions for the full-length 32P DSC model are identical to those described in Appendix A of [4]. The active fuel length for the CCNPP DSCs is 136.7" as listed in Table 1.2-1 of [9].

4.3 Material Properties

4.3.1 24P DSC Model

The same thermal properties listed in Table 4-1 of [3] are used for the CCNPP 24P DSC model in this calculation with the exception of the following:

- The material representing for cavity gas including the related gaps is replaced by air,
- The fuel effective conductivities are based on vacuum drying case with air fill as listed in Table 4-1 and Table 5-2 of [3].

4.3.2 32P DSC Model

The same thermal properties, listed in Appendices B and C of [4], are used for the 32P DSC model in this calculation with the exception of the following:

- The material representing for cavity gas is replaced by air,
- The effective conductivities for the gaps listed in Appendix C of [4] are recalculated based on air conductivity,
- The radial fuel effective conductivity is determined in Section 6.0 of [5] for the case of vacuum drying with air backfill.

5.0 METHODOLOGY

The same methodology discussed in Section 5.0 of [3] is used for the 24P DSC model and the same methodology discussed in Section 4.0 of [4] is used for the 32P DSC model in this calculation.

6.0 COMPUTATIONS

6.1 24P DSC Analysis Models

The half-symmetric, three-dimensional finite element model of the 24P DSC is developed using ANSYS Version 10.0 [8]. The model contains the DSC shell, guide sleeve, spacer disc, support rods and homogenized fuel.

The 24P DSC analysis model is described in Section 5.1 of [3] and shown in Figure 6–1.

6.2 32P DSC Analysis Model

The three-dimensional quarter-symmetry finite element model of 32P DSC was developed using ANSYS Version 5.6 [4]. ANSYS Versions 10 is used in this calculation for the analysis of the 32P DSC.

The 32P DSC analysis model is described in Appendix A of [4] and shown in Figure 6–1.

6.3 Heat Generation and Boundary Conditions

The decay heat load for both DSC models is multiplied by a peaking factor of 1.08 [1] and is modeled as a heat generation within the active fuel region and the slice model.

The heat generation used is computed as follows:

$$q''' = \frac{Q}{n \times L_a} * PF$$

Q = decay heat load, Btu/hr,
n = number of fuel assemblies = 24 for 24P DSC or 32 for 32P DSC,
L_a = active fuel length = 136.7 in,
PF = peaking factor = 1.08.

The DSC shell temperature profiles for 4 kW and 6 kW heat loads directly retrieved or interpolated from two heat loads of 2 kW and 6 kW calculated in [6] are mapped into the 24P and 32P DSC models as boundary conditions.

The 24P DSC model only includes 2 half spacer discs and has adiabatic boundary conditions on the axial boundaries. The DSC shell temperatures in the 24P DSC model are mapped from the hottest section of the 24P DSC shell temperature profile.

Typical heat generation loads for the 24P and 32P DSC models are shown in Figure 6–2 and Figure 6–3, respectively.

6.4 Fuel Oxidation Time Limit

The fuel rods in the CCNPP DSCs may hypothetically be exposed to air once DSC through wall crack propagation occurs from SCC. If the temperature of the fuel rods is high enough and if the time is sufficient for UO_2 to oxidize to U_3O_8, then a stress is placed on the fuel rod cladding because of the reduction in fuel density from 10.4 g/cm^3 to 8.4 g/cm^3 [7]. Such stress can cause the cladding to be compromised and split open.

Since the containment capability of cladding is of interest, the incubation time is defined as the time when cladding defects start to propagate. The correlation between incubation time and temperature are studied in detail by EPRI [7].

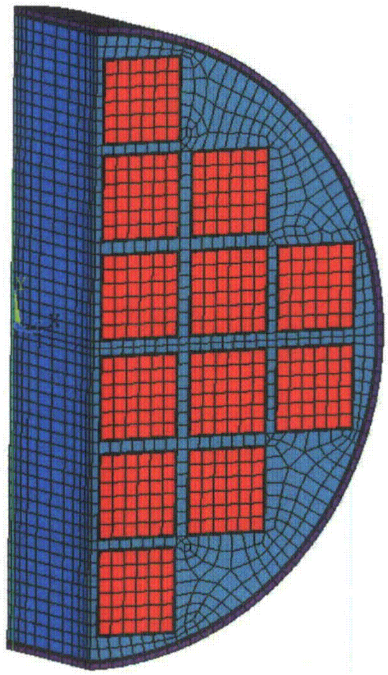
EPRI tests predict a logarithmic correlation between the incubation time and the reverse of the absolute temperature shown in [7], Figure 3-9. The data taken from this figure is represented in Table 6-1. Using the best fit curve methodology illustrated in Figure 6–4, the following correlation is retrieved between the incubation time and temperature from EPRI data [7].

$$\log t_{inc} = 10108 \times \frac{1}{T_{fuel,max}} - 15.662$$

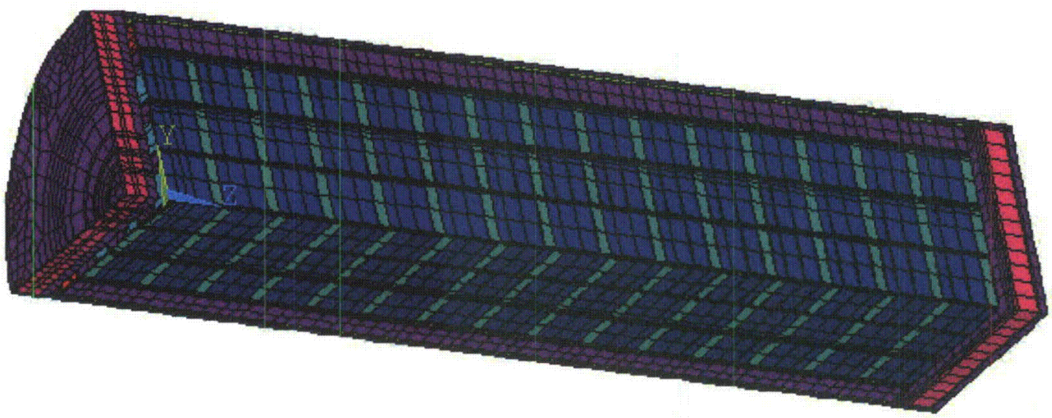
t_{inc} = incubation time (hr)
$T_{fuel,max}$ = absolute temperature (K)

Table 6-1 Data for Incubation Time [7]

$\log t_{inc}$ (t_{inc} in hr)	$1/T_{fuel,max}$ (1/K)
0.5128	1.6E-3
1.5128	1.7E-3
2.5436	1.8E-3
3.5385	1.9E-3



(a) 24P DSC Model



(b) 32P DSC Model

Figure 6–1
Finite Element Models of 24P and 32P DSCs

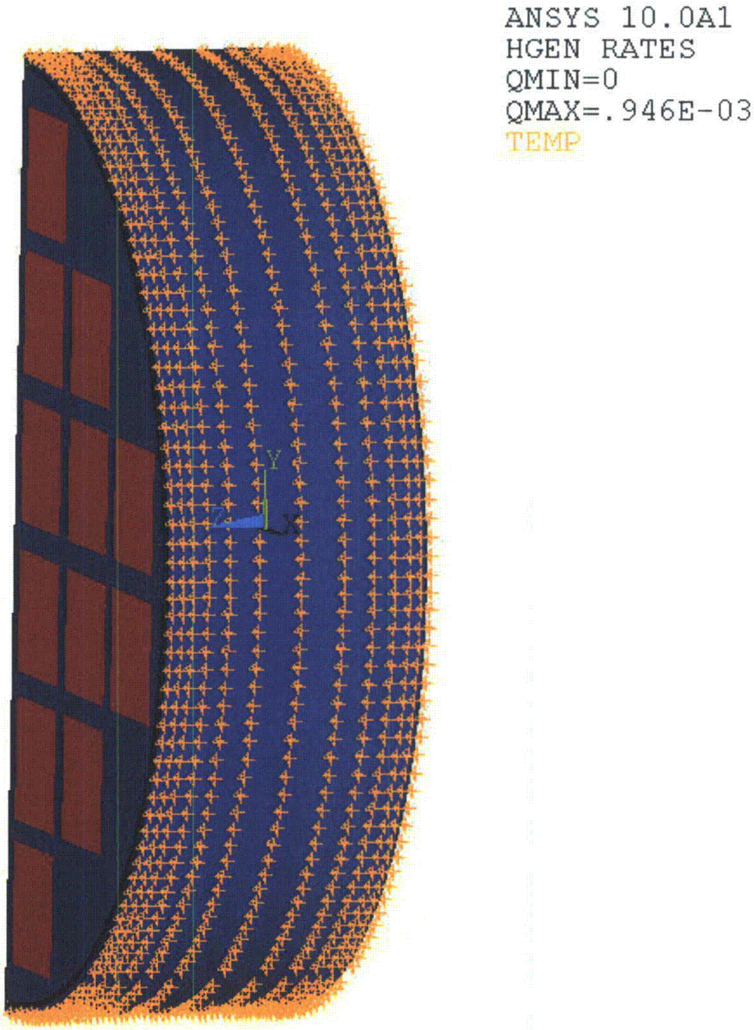
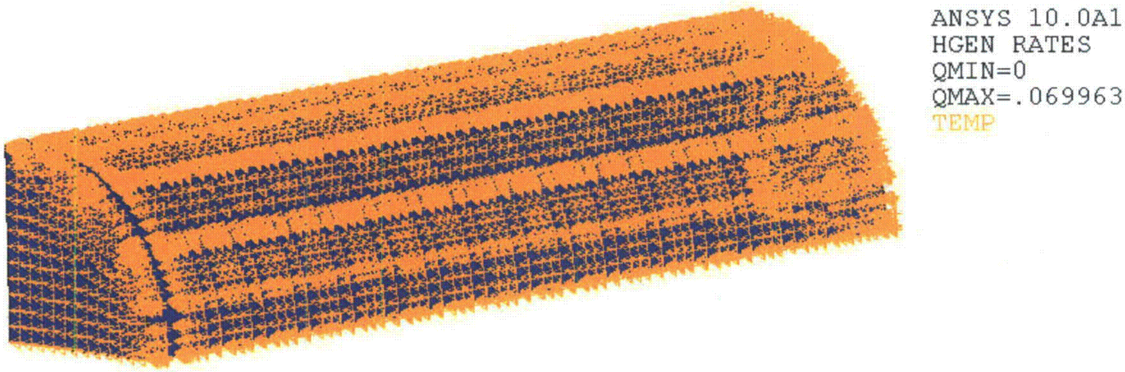


Figure 6–2
Heat Generation and Boundary Condition for 24P DSC Model (4 kW Heat Load)



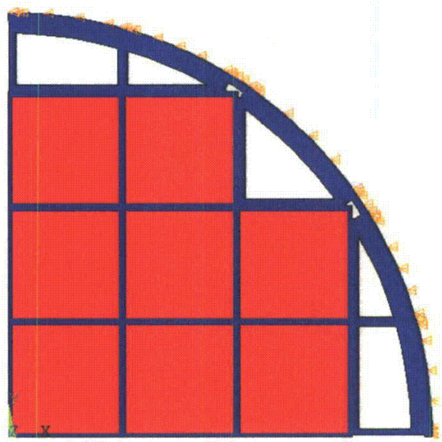


Figure 6–3
Heat Generation and Boundary Conditions for 32P DSC Model (6 kW Heat Load)

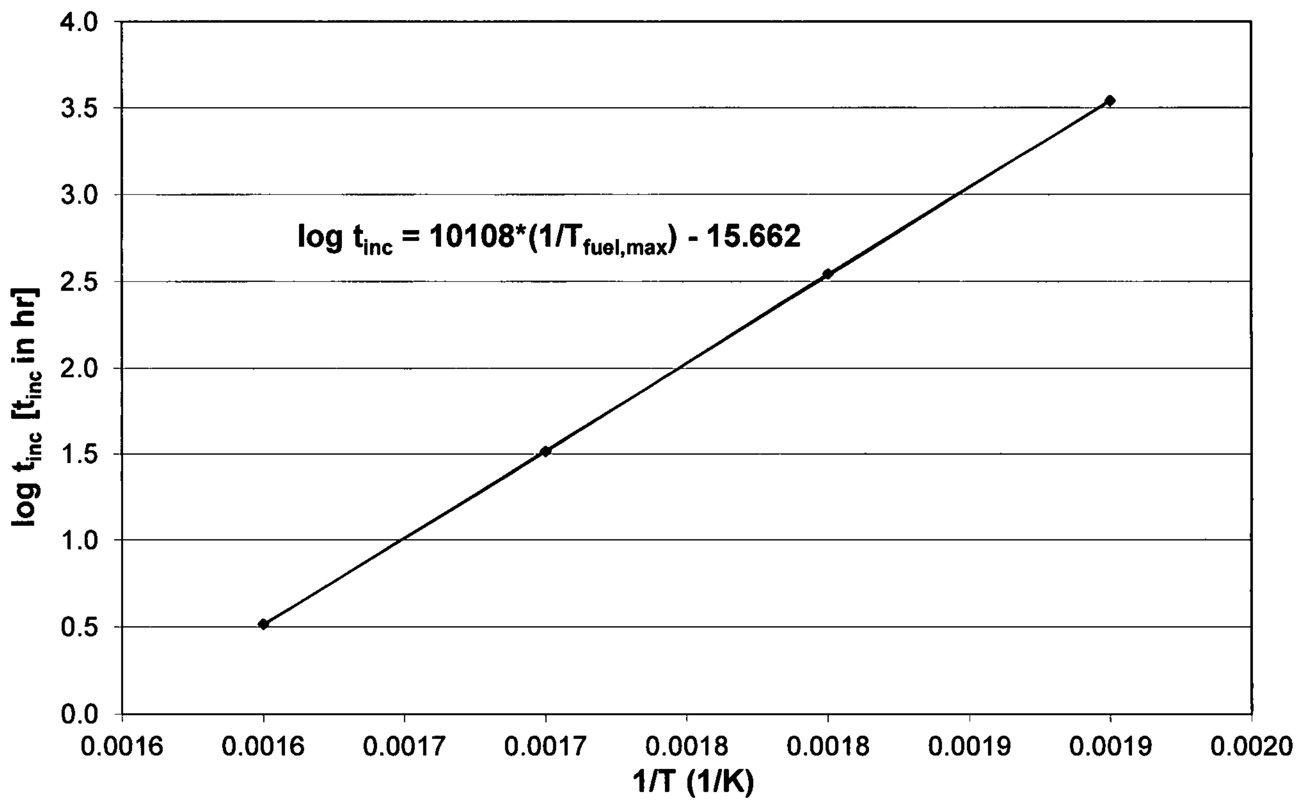


Figure 6–4
Best-Fit Curve for Incubation Time Data from [7], Figure 3-9

6.5 List of Input/Output Files

All the runs are performed using ANSYS version 10.0 [8] with operating system "CentOS 5.4 x64", and CPUs "Opteron 200 Series" or "Xeon 5000 Series" or "Xeon 7000 Series".

The ANSYS runs are summarized in Table 6-2.

Table 6-2 Summary of ANSYS Runs

Run Name	Description	Date / Time for Output File
24P_Model	24P DSC Model Generation	03/26/2013 05:01 PM
Tmap_24P_4kw	Mapping DSC Shell Temperatures for 4 kW Heat Load to 24P DSC Model	04/01/2013 09:47 AM
24P_4kw	24P DSC Thermal Analysis, Normal Storage, 4 kW Heat Load	04/01/2013 09:58 AM
Tmap_24P_6kw	Mapping DSC Shell Temperatures for 6 kW Heat Load to 24P DSC Model	04/10/2013 10:32 AM
24P_6kw	24P DSC Thermal Analysis, Normal Storage, 6 kW Heat Load	04/10/2013 10:42 AM
Tmap_32P_4kw	Mapping DSC Shell Temperatures for 4 kW Heat Load to 32P DSC Model	04/01/2013 12:18 PM
32P_4kw	32P DSC Thermal Analysis, Normal Storage, 4 kW Heat Load	04/01/2013 12:27 PM
Tmap_32P_6kw	Mapping DSC Shell Temperatures for 6 kW Heat Load to 32P DSC Model	04/10/2013 09:31 AM
32P_6kw	32P DSC Thermal Analysis, Normal Storage, 6 kW Heat Load	04/10/2013 09:43 AM

ANSYS macros, and associated files used in this calculation are shown in Table 6-3.

Table 6-3 Associated Files and Macros

File Name	Description	Date / Time
CCBasket.db	32P DSC Model	[4]
CCNPP-HSM-C1-kW.cdb	DSC Shell Temperature for 6 kW Heat Load	[6] (1)
CCNPP-HSM-C5-kW.cdb	DSC Shell Temperature for 2 kW Heat Load	
Cladding-Oxidation.xls	Excel file to compute the incubation time	04/11/2013 02:46 PM

Note (1): The shell element "SHELL131" in the CDB files from Table 7-2 of [6] is changed to "SHELL57" for the input data in mapping DSC temperatures for 4 kW heat load.

7.0 RESULTS

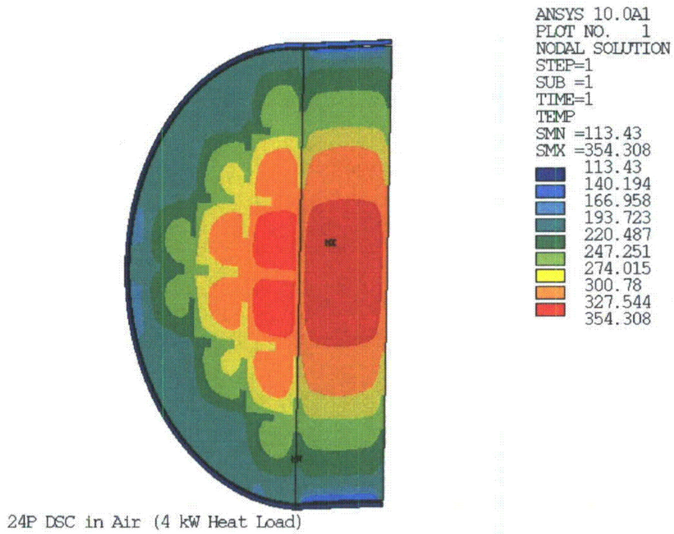
Table 7-1 presents the maximum fuel cladding temperatures for 4 kW and 6 kW heat loads for the CCNPP 24P and 32P DSCs, respectively. Figure 7-1 and Figure 7-2 present the temperature contours in the CCNPP 24P and 32P DSCs.

The fuel rods within the CCNPP 24P and 32P DSCs may hypothetically be subjected to exposure to the oxidizing atmosphere due to SCC during long-term storage at the CCNPP ISFSI site. The incubation times for the CCNPP 24P and 32P DSCs for 4 kW and 6 kW heat loads are calculated based on the discussion presented in Section 6.4 and listed in Table 7-1.

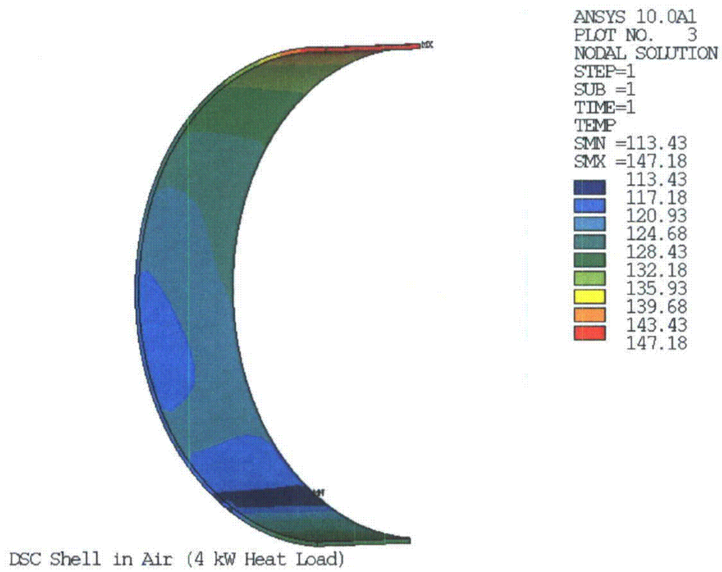
Table 7-1 CCNPP DSC Maximum Temperatures for 4 kW and 6 kW Heat Loads

24P DSC			
Heat Load, kW	**Total cooling Time , Year [6], Appendix B (1)**	**Maximum Fuel Cladding Temperature, °F**	**Incubation time (time to split), Year**
6	28	447	2.9
4	54	354	571
32P DSC			
Heat Load, kW	**Total cooling Time , Year [6], Appendix B (1)**	**Maximum Fuel Cladding Temperature, °F**	**Incubation time (time to split), Year**
6	45	399	38
4	90	306	14,399

Note (1): Cooling time is calculated using equations from [11], Table A.1.4.1-6. The cooling time may vary based on the DSC loading.

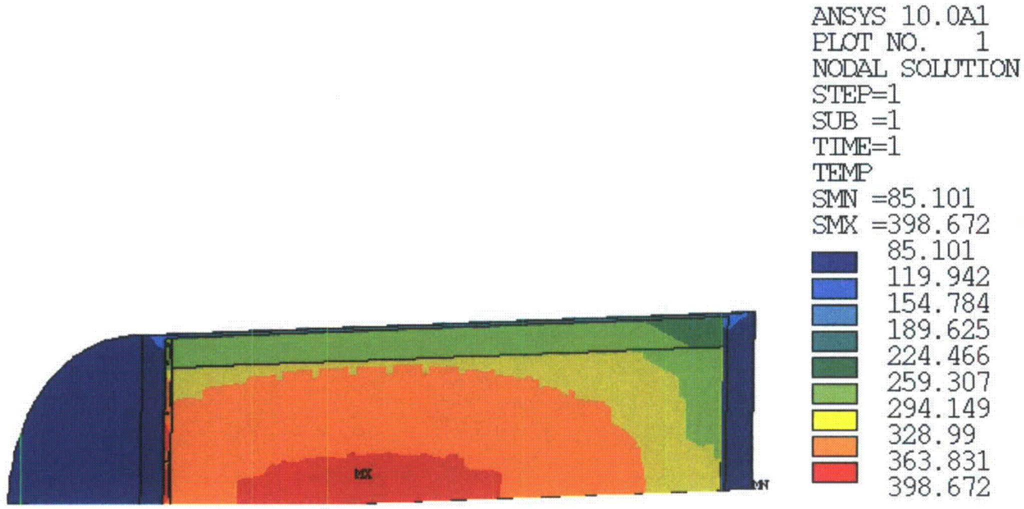


24P DSC Model

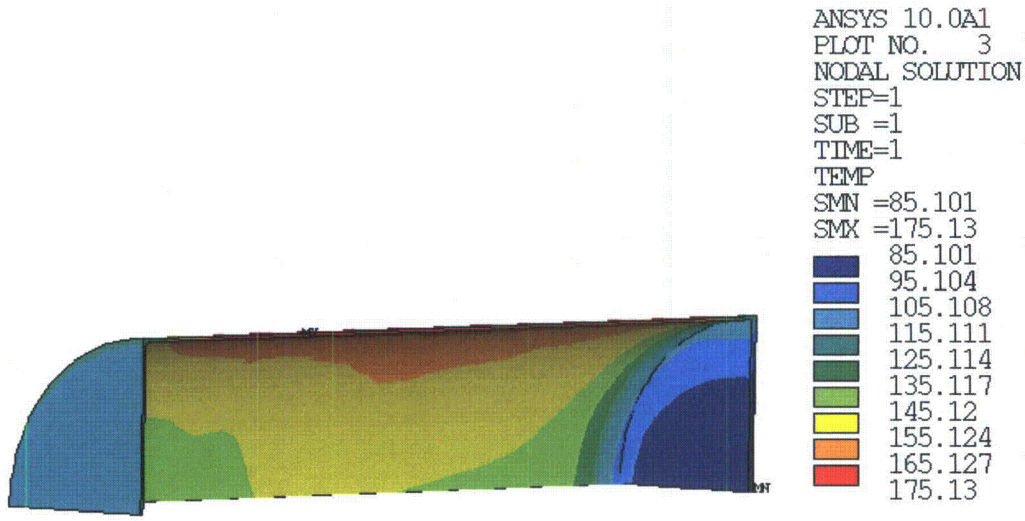


DSC Shell

Figure 7-1 Temperature Distribution of 24P DSC, Normal Storage, 70°F Ambient, 4 kW Heat Load



32P DSC Model



DSC Shell

Figure 7-2 Temperature Distribution of 32P DSC, Normal Storage, 70°F Ambient, 6 kW Heat Load

8.0 CONCLUSION

Based on Table 7-1, the expected maximum fuel cladding temperatures after long-term storage for the CCNPP 24P and 32P DSCs at the CCNPP ISFSI site are less than 354°F for the 24P DSC and less than 399°F for the 32P DSC.

In the hypothetical case that the fuel cladding becomes exposed to the oxidizing atmosphere due to SCC after long-term storage at the CCNPP ISFSI site, the expected time at which the fuel cladding may become comprised and split open on air exposure is more than 571 years for the 24P DSC (up to 4 kW heat load) and more than 38 years for 32P DSC (up to 6 kW heat load).

The above conclusions are valid for any 24P DSC and 32P DSC with maximum heat loads below 6 KW at CCNPP ISFIS site regardless of the storage time since the maximum heat loads as the used as inputs in the evaluation.

ATTACHMENT (2)

REGULATORY COMMITMENT

Calvert Cliffs Nuclear Power Plant, LLC
June 14, 2013

ATTACHMENT (2)

REGULATORY COMMITMENT

The table below lists the action committed to in this submittal. Any other statements in this submittal are provided for information purposes and are not considered to be regulatory commitments.

Regulatory Commitment	Date
Create an Aging Management Program for the ISFSI DSCs that encompasses the inspections discussed in our Response to RAI E-2.	10/30/2014